Atomic Physics at SPring-8 and New SUBARU

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1. Introduction

SPring-8 (Super Photon Ring, 8 GeV) and New SUBARU are now in operation as a synchrotron radiation facility complex in Harima Science Garden City in Hyogo prefecture locating 100 km west of Osaka. As shown in Fig. 1, SPring-8 is composed of a 1.0 GeV electron/positron injector linac, an 8.0 GeV booster synchrotron and an 8.0 GeV storage ring with a circumference of 1436 m, while New SUBARU is 1.5 GeV storage ring of 119 m circumference with electrons being injected from Spring-8 linac. [1,2]

SPring-8 was constructed by the joint team of the Japan Atomic Energy Institute (JAERI) and the Institute of Physical and Chemical Research (RIKEN), and, for the facility operation, the Japan Synchrotron Radiation Insitute (JASRI) has the responsibility. New SUBARU was constructed and has been in operation by Laboratory of Advanced Science and Technology for Industry, Himeji Institute of Technology (LASTI/HIT).

2. Specifications of the synchrotron radiation sources

SPring-8 storage ring is designed to have a 4-fold symmetric structure with 40 straight sections of length 6 m and four straight sections of length 30 m. It can accommodate 38 beam lines from insertion devices (ID), including four long ID, and 23 beam lines from the bending magnets. The length of the standard beam line is 80 m, though several beam lines can be expanded up to 300 m and 1000 m. Fig. 2 shows spectral brilliance for a typical source of SPring-8 estimated at the designed phase. The brilliance of about 10^{20} photons / (s.mm^2.mrad^2.0.1% band width) was estimated to be obtained at the designed electron current of 100 mA with standard undulators. The observed horizontal emittance was equal to the designed value of 7 nm.rad.

New SUBARU is a hexagonal race-track type ring composed of six unit structures of double-bend achromatic cell with two 34-degree bending magnets (BM) and one inverted bending magnet (IBM) in the middle in each cell. Introducing IBM, a momentum compaction factor can be varied from –0.001 to +0.001 without large change of emittance and Twiss parameters, giving several benefits such as short pulse of synchrotron radiation by short bunched electron beam, stable and reliable control, lower RF power and so on. Bunch length of 7.76 mm (26 ps) can be expected. The emittance is 67 nm.rad at 1.5 GeV and 30 nm.rad at 1.0 GeV. There is a limitation in principle in reducing the emittance because of limited number of main bending magnets (12) due to small circumference. Nonetheless the maximum brilliance is estimated as high as 10^{18} photons / (s.mm^2. mrad^2.0.1% band width) with a 11-m long undulator set in one of the long straight sections as shown in Fig. 3.

3. Research activities in atomic physics

Some experimental works were already published in journals, and, also, several works are progressing or in planning in Spring-8 and New SUBARU. Some of the representative topics among those are introduced in this paper.

3.1 Photoionization of Ne^{3+} ions in the region of the 1s .> 2p autoionizing resonance

Photoion yields of Ne^{4+} from Ne^{3+} were successfully measured in the region of the 1s .> 2p autoionizing resonance by a photon-ion merged-beam technique. A broad structure centered at 864.5 eV, which is composed of several transitions, was observed in the photon-yield spectrum. The spectrum was analyzed with the results of multiconfiguration Dirac-Fock calculations. The calculations revealed that the lines contained in the broad structure can be attributed to possible transitions from $2s^2 2p^3\ ^4S_{3,2}$, $^2D_{3,2}$, and $^2D_{5,2}$ initial levels. The calculated spectrum satisfactorily shows an overall agreement with the experimental one. [3]

Photoionization of Ne^{2+}, Ne^{1+} and O^{1+} were also investigated.

3.2 Double K hole production for heavy atoms

Hypersatellite X-rays emitted in deexcitation process of double K hole produced by X-ray excitation were measured with a wavelength dispersion X-ray analyzer for Ti, V, Ca and others. The intensity ratios of hyperfinesatellite $K\alpha^h$ and $K\alpha$ were obtained as a function of primary photon energy. Comparison of the result with Thomas model calculation shows general agreement with some discrepancy. The detailed analysis is under way. [4]

3.3 Sub-natural-width angle-resolved resonant Auger electron spectroscopy of atoms and molecules on the high resolution soft X-ray monochromator at Spring-8

A high resolution electron spectroscopy apparatus on the soft X-ray beam line BL27SU at Spring-8 was installed, and the sub-natural-width angle-resolved resonant Auger spectroscopy of atoms and molecules has been started. It is demonstrated that the sub-natural-width spectroscopy is a powerful tool both for spectroscopic investigation of the Auger final states and for investigation of the nuclear motion dynamics in the core-excited molecules, presenting some results for the Ne 1s .> 3p excitation and for the C and O 1s excitations of CO_2 to the lowest unoccupied molecular orbital $2\pi_u$. [5]

3.4 High resolution measurement for the resonant Auger emission of Xe following $3d_{5.2}$.> 6p excitation

Angle-resolved resonant Auger spectra for the transitions Xe $3d^{-1}{}_{5.2}\,6p$.> $4d^{-2}\,np$ were recorded with optical and electron energy band widths narrower than the lifetime widths of the Auger initial and final states. All the multiplet structures were resolved for the ionic core $4d^{-2}$ of the spectator Auger final states and assigned as $4d^{-2}\,{}^1S_0$ np, ${}^1D_2$ np, ${}^1G_4$ np, ${}^3P_{0,1,2}$ np, and ${}^3F_{1,2,3}$ np n = 6,7 by comparison with previous measurements and calculations for the corresponding normal Auger emission. The resonant Auger anisotropy parameters obtained from the angular distribution measurements agreed well with those expected from the spectator model. [6]

3.5 High resolution angle-resolved measurements of Auger emission from the photo-excited $1s^{-1}$ 3p state of Ne

Measurements of the resonant Auger electron emission at an electron kinetic energy of ~810 eV in the Ne atom following 1s .> 3p excitation at an excitation photon energy of 867.12 eV, with a photon band pass of 60-68 meV, an electron energy resolution of 13 meV, and the Doppler width due to thermal motion of the sample Ne atoms of 79 meV were made. Under these conditions, the overall resolution of 100-105 meV (FWHM) is much smaller than the natural width, 250 meV, of the Ne 1s hole state, and the resonant Auger final states $2p^{-2}({}^1D_2)$ 3p(or 4p) ${}^2P$, ${}^2D$, ${}^2F$ were completely resolved. The obtained β values and branching ratios were in good agreement with first principles calculations by means of the multi-configuration Dirac-Fock methods within the framework of the two-step model. [7]

3.6 Direct probe of the bent and linear geometries of the core-excited Renner-Teller pair states by means of the triple-ion-coincidence momentum imaging

The doubly-degenerate core-excited Π state of CO_2 splits into two due to vibronic coupling with the bending motion. As a direct probe of this Renner-Teller effect, the bend and linear geometries of the lower and higher states, respectively, were measured by means of the triple-ion-coincidence momentum imaging. The excitation ratio of the lower bent state to the higher linear state decreased with the increase in the excitation photon energy. [8]

3.7 Probing bond angle changes by triple ionic fragmentation of CO_2: A direct proof for the validity of the (Z+1) model

Linear momenta of the three fragment ions C^+, O^+, and O^+ produced via the triple ionization of CO_2 were measured in coincidence. Distributions of the O-O angle between the momenta of the two O^+ ions suggest that the stable geometries of CO_2 in the C $1s^{-1}2\pi_u$ core-excited state and the C $1s^{-1}$ core-ionized state are bent and linear, respectively, illustrating the validity of the (Z+1) model. [9]

3.8 Gamma-rays produced by Compton backscattering in BL1 at New SUBARU

Backward Compton scattering of laser light from 1.0 GeV electron beam was investigated in the 14-m long straight section (BL1). The laser light with 1064 nm wavelength from YAG laser was used. The backward γ-ray photons were collimated in 0.67 mrad and detected by a 3”ϕ x 3”ϕ NaI(Tl) scintillator. The photon yields observed with 10 mA electron beam and 0.36 W laser power was about 4 x 10^4 photons / s in the energy range of 7 MeV to 17.5 MeV which was in fairy good agreement with a simulation calculation using the EGS4 code. The Compton backscattering system was installed for the purpose of opening-up the possibilities for basic research and application using the produced high energy monochromatic polarized photons. [10]

3.9 Nuclear excitation by electronic transition (NEET) experiment

The NEET, the process of nuclear excitation by means of direct energy transfer from the excited atomic shell to the nucleus via a virtual photon, was investigated in ^{189}Os. In case of ^{189}Os, an initial K-vacancy state decays from the 70.82 keV(M1), 71.84 keV(E2) and 71.91 keV(E2) states of M-shell, and the 69.537 keV nuclear state (5/2$^-$) in ^{189}Os is excited. The state decays to the 30.81 keV metastable state, which, then, decays by internal conversion (L and M). The L X-rays were measured as a signature of the NEET. Monochromatic 115 keV X-ray beam in the BL08W at Spring-8 was used to produce the K-vacancies. After irradiation, the Os L X-rays were detected with Ge LEPS for 15 hours. There was a few Os L X-rays within the sensitivity of the measurement. It seems the NEET probability is lower than ones obtained previously. The detailed analysis is in progress. [11]

References

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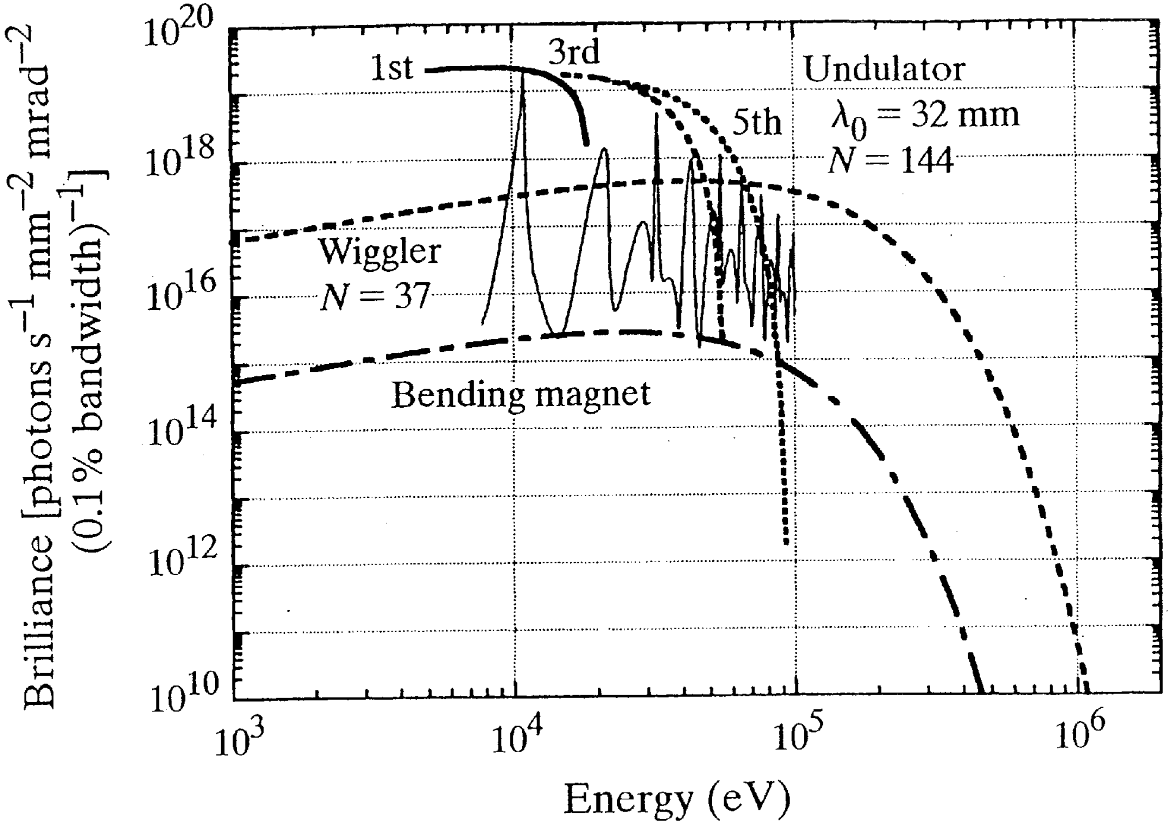
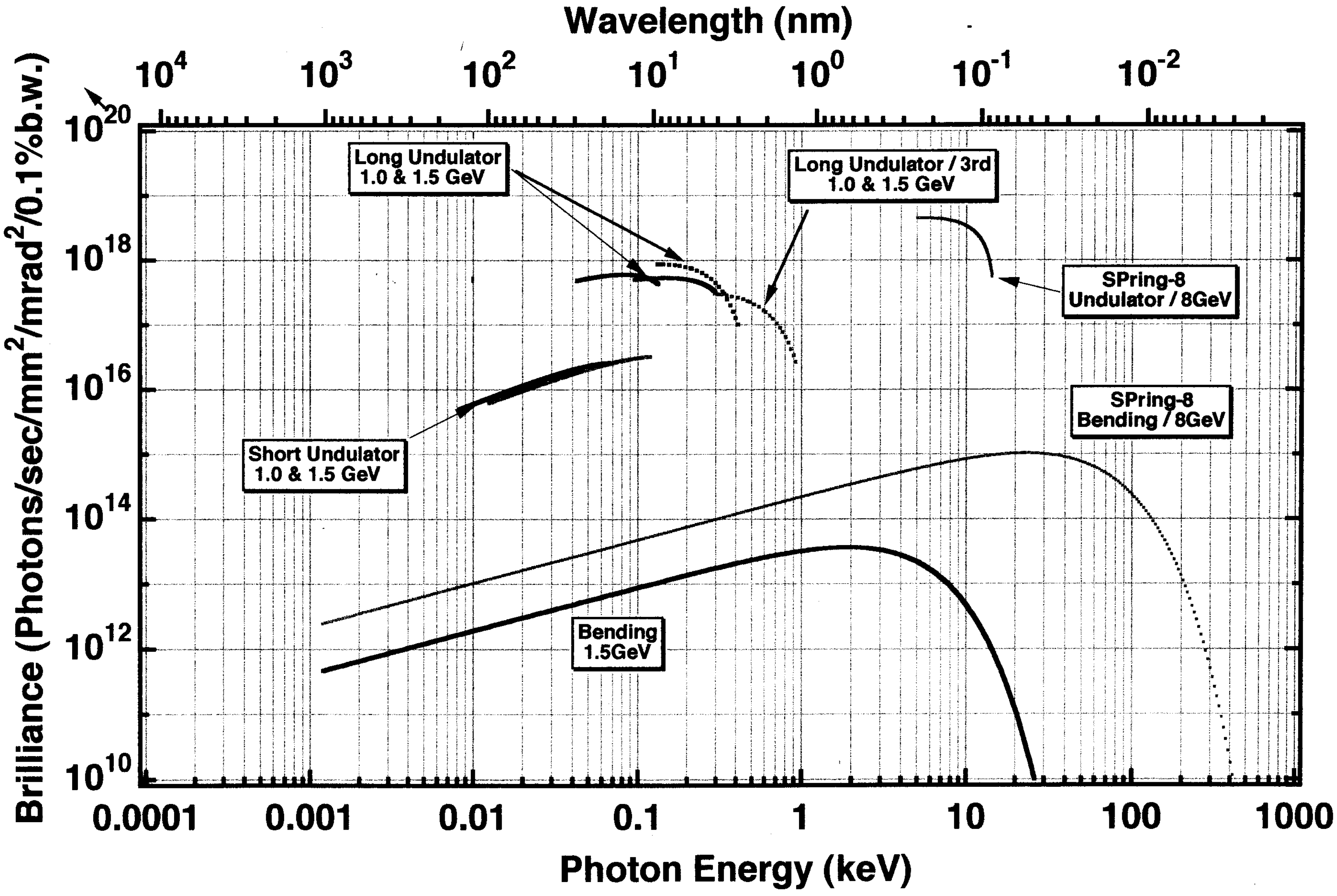
The SPring-8 Campus

SPring-8 has three accelerators (a "Linac" linear accelerator, synchrotron and storage ring) and scope for 61 beamlines. Campus buildings include a Biomedical Imaging Center, research-related facilities (RI Laboratory, Machine Laboratory, Accelerator and Beamline R&D Facility), utility supply installations, a cafeteria and guest house.



The spectral brilliance of the Spring-8 bending magnet, wiggler and undulator, calculated assuming 6 nm rad emittance, 10% coupling and 100 mA stored current.


Wavelength (nm)
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
Brilliance (Photons/sec/mm^2/mrad^2/0.1%b.w.)
10^20
10^18
10^16
10^14
10^12
10^10
Long Undulator 1.0 & 1.5 GeV
Long Undulator / 3rd 1.0 & 1.5 GeV
SPring-8 Undulator / 8GeV
SPring-8 Bending / 8GeV
Short Undulator 1.0 & 1.5 GeV
Bending 1.5GeV
0.0001
0.001
0.01
0.1
1
10
100
1000
Photon Energy (keV)